



NASA and Underwriters Laboratories Collaboration on Simulated Internal Short Test for Lithium-ion Cells

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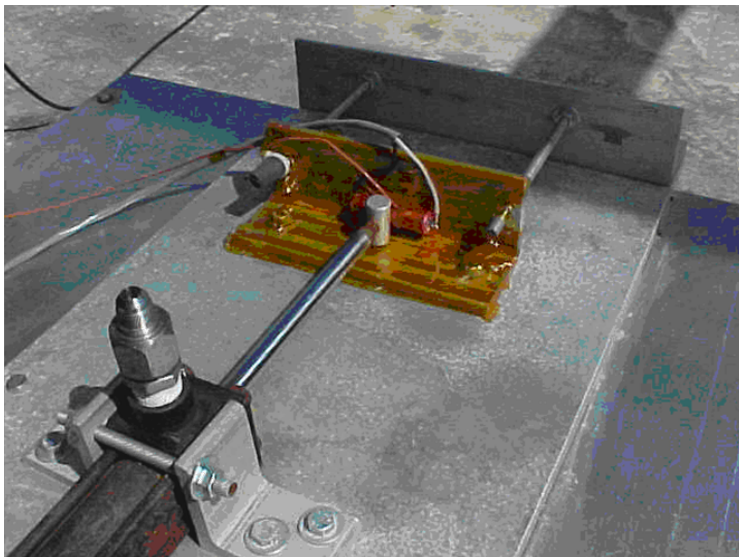
Underwriter's Laboratories

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Background

- Simulation of internal shorts using a crush test method has been used for more than 13 years at NASA-JSC
- The equipment used a hydraulic press with manual operation.
- Initial tests were carried out with crushing until voltage fell to 0 V; then later changed to 500 mV drop in voltage
- Not easy to control; but repeatable results obtained



- * Cells of different chemistries (NiMH vs Li-ion (cobaltate vs spinel vs phosphate))
- * Cells tested at different states of charge
- * Results were repeatable and reproducible

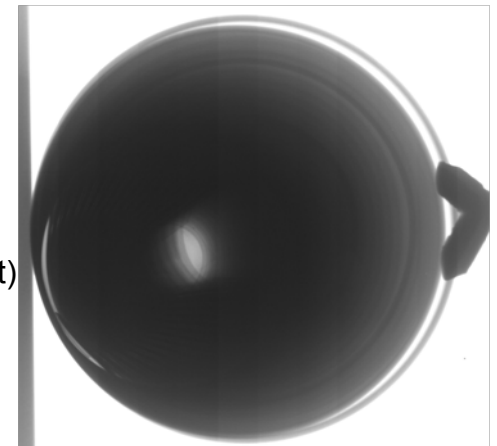
Collaboration with UL

- UL involvement started from the standards working groups and presentation of NASA-JSC data at the meetings.
- Other methods and techniques were also under review such as the BAJ and the UL Blunt Nail Crush (BNC) test.
- Since the UL test is similar to NASA-JSC method, UL was interested in a collaboration.
- A Space Act Agreement was signed between NASA and UL to carry out the work.
- A test plan was provided by NASA as part of the agreement.
- UL provided the test equipment as part of the agreement.
- Several other objectives and tasks were also included such as DPAs, X-ray, CT, etc.

Work Plan

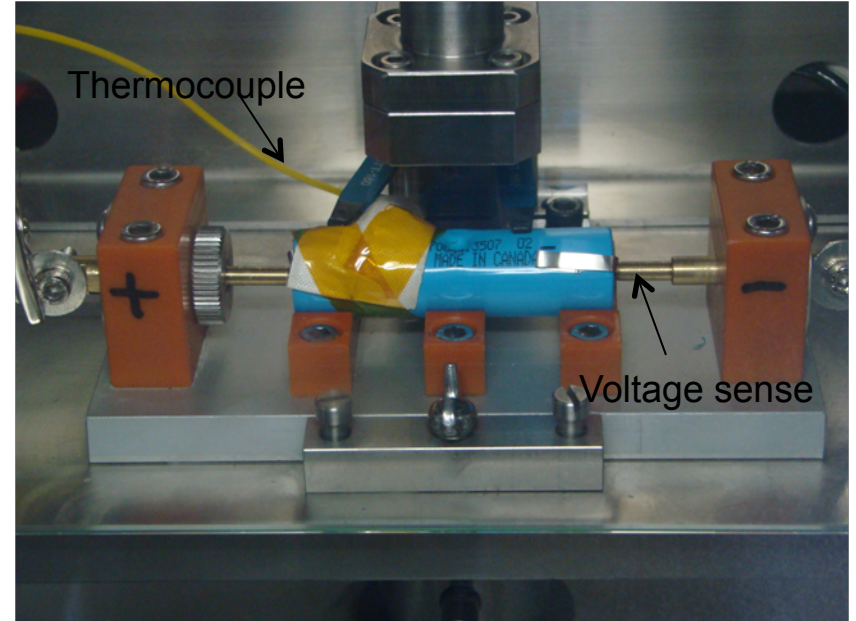
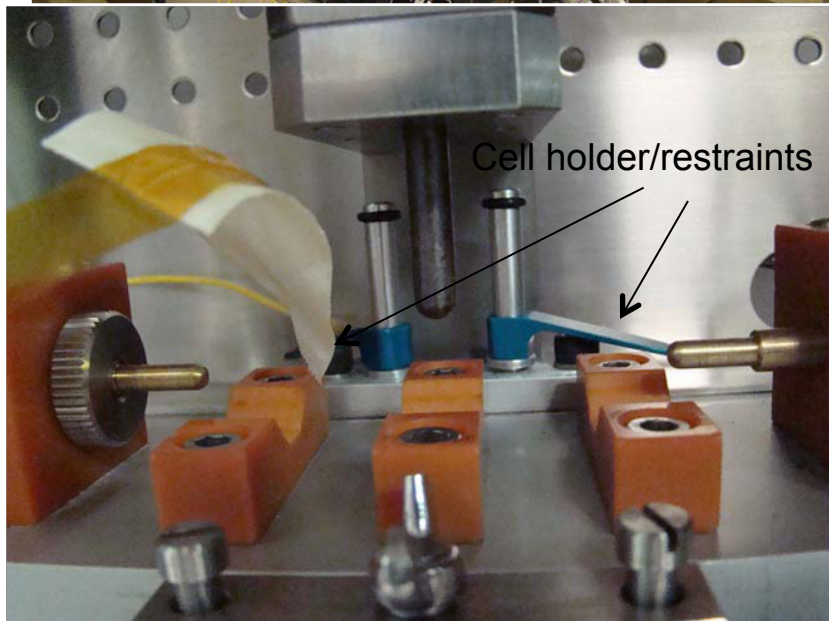
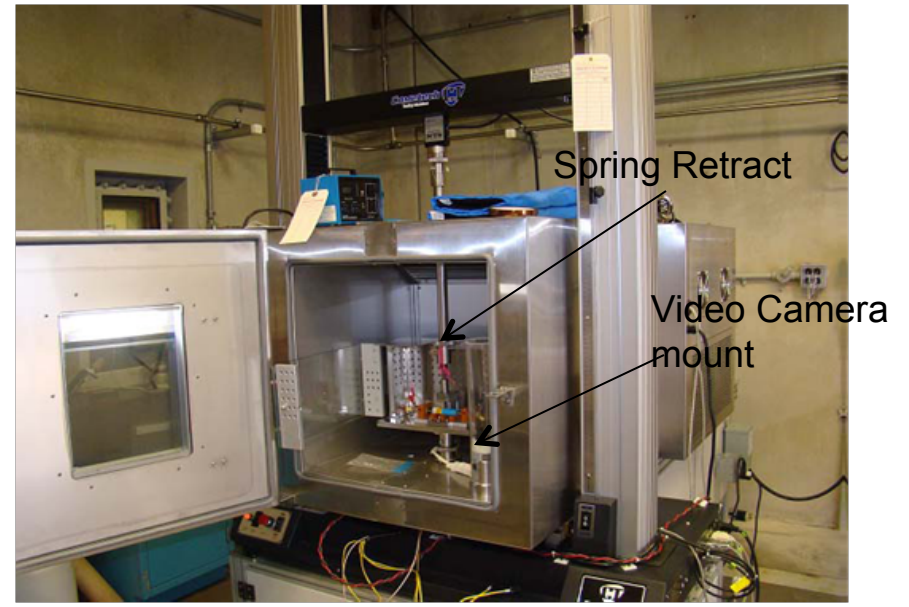
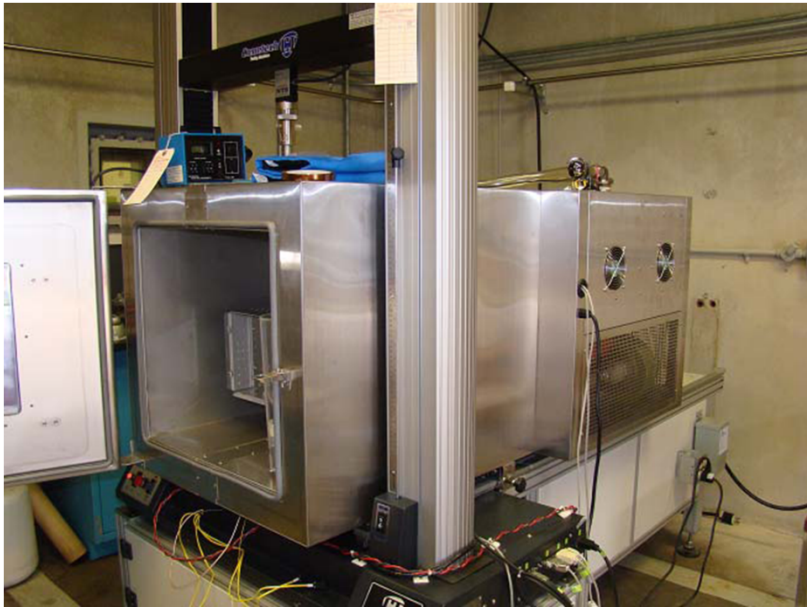
The following plan was formulated with several variables to be studied.

- Cells were subjected to different test protocols before crushing with the blunt rod.
 - Fresh cells (2 cycles only)
 - 200 cycles
 - 500 cycles
 - 1000 cycles
 - Cells rejected from a battery manufacturer
 - Cells cycled at low temperatures
 - Cells cycled at 2 C charge rates
 - Cells cycled to high voltages (4.5 V)
- All cells X-rayed to mark the location of current collector tab.
- Variables:
 - Rod diameter
 - Radius of curvature of the rod tip
 - Rate of displacement (0.1 mm/sec to 0.01 mm/sec)
 - Orientation of cell (location of Al current collector versus location 90 degrees to that)
 - Cell SOC
 - Voltage change for test stoppage (100 mV vs 500 mV)



All cells were Sony 18650 cells except two sets used at the start of the program that were used to optimize the diameter of the rods and rate of displacement. The Sony cells were only test vehicles and not to be construed as endorsement or problematic.

Simulated Internal Short Test Equipment at NASA-JSC



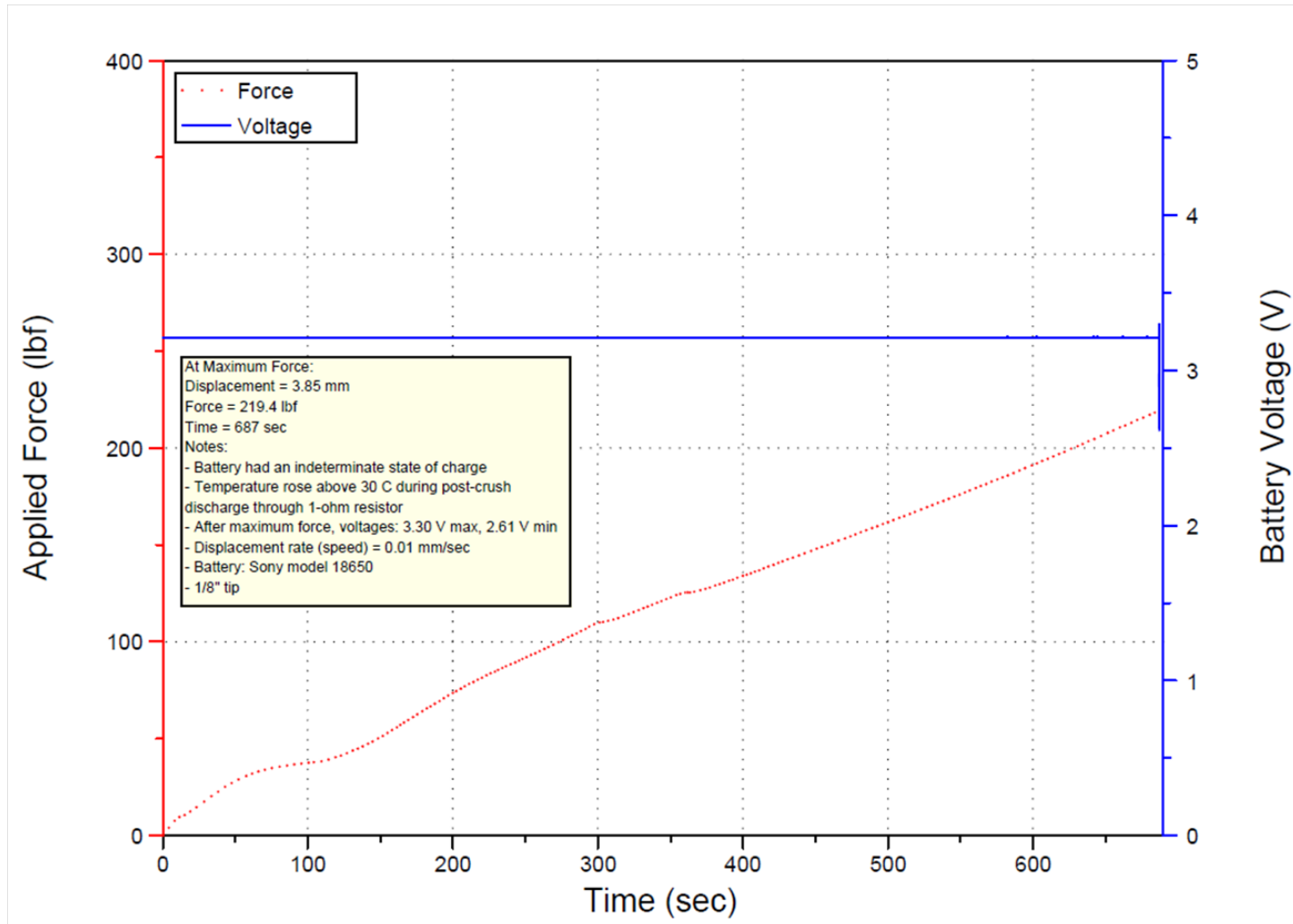
CT Scan Work

- CT scans were carried out on all the cells that were not compromised (that is, no breach of cell can)
 - All cells that did not undergo a vent or disassembly during the simulated short test were discharged after test completion and test chamber purged with inert gas for at least 4 hours. Temperatures were always checked before cells were removed from test stand.
- Each CT slice through the cell represents a 30 to 50 micron thick layer

Initial Tests

- The first trials were carried out on fully discharged cells using a speed of 0.1mm/sec and rods of two diameters namely 1/8" and 1/4".
- We found that the 1/4 and 1/8" rod penetrated the can when tested at a speed of 0.1mm/sec.
- The second set of tests involved changing the rate of crush in increments down to 0.01 mm/sec. The 0.01mm/sec rate seemed to provide results that did not cause the compromise of the can.
- Tests were then conducted with 0.01 mm/sec rate of crush with the rods of 1/4" and 1/8" diameters.
- Voltage limit was 500 mV drop.

Cell 63



CT images Cell 63 1/8" rod

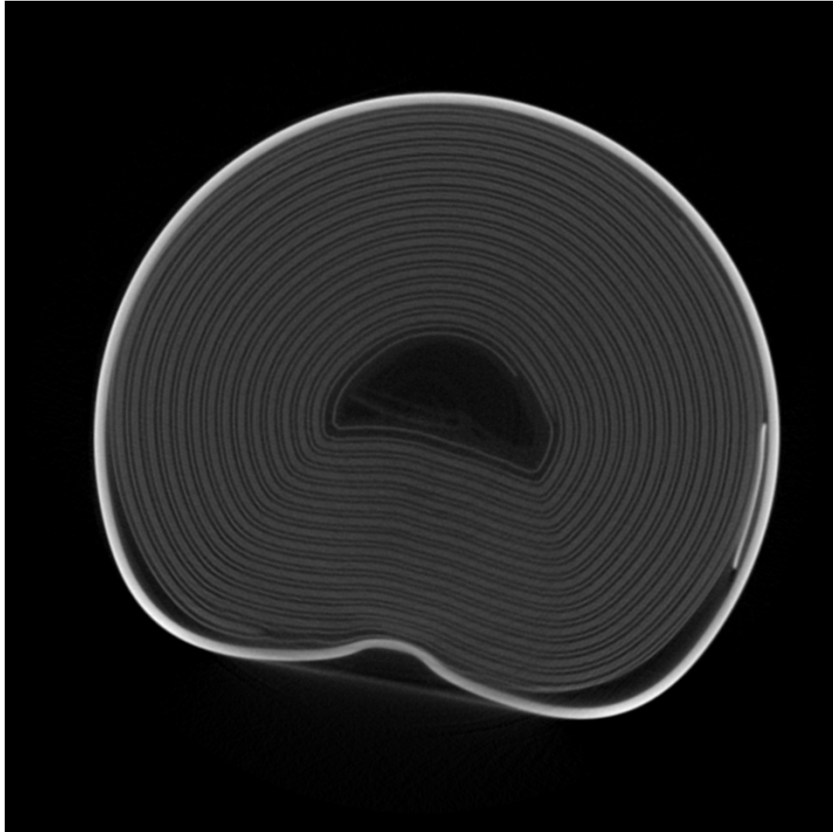


Image 570

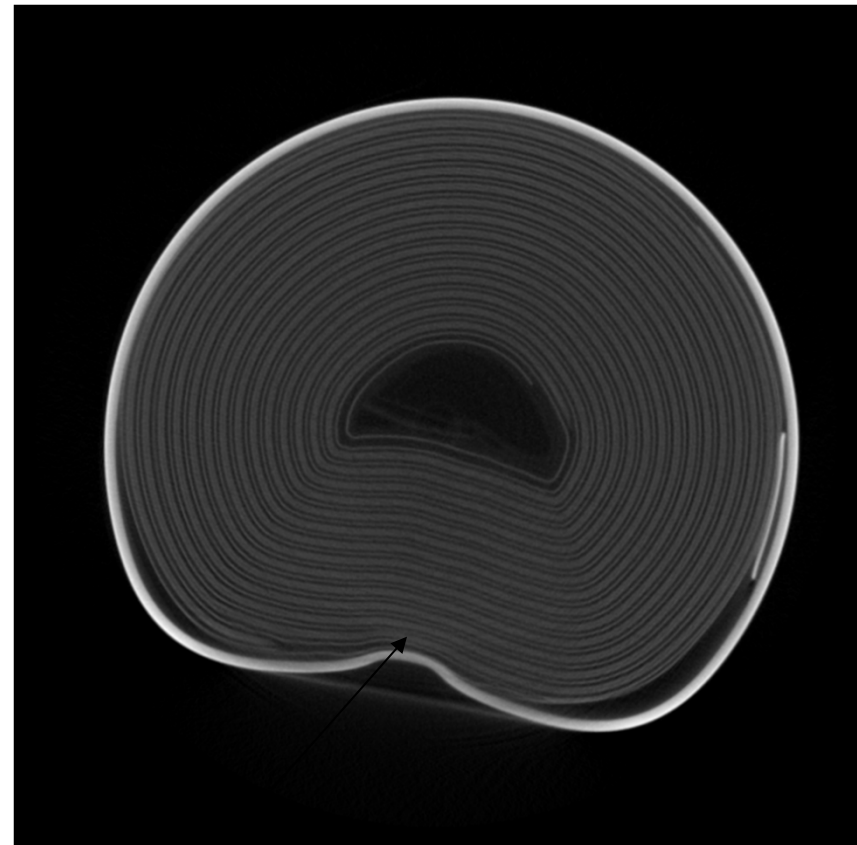
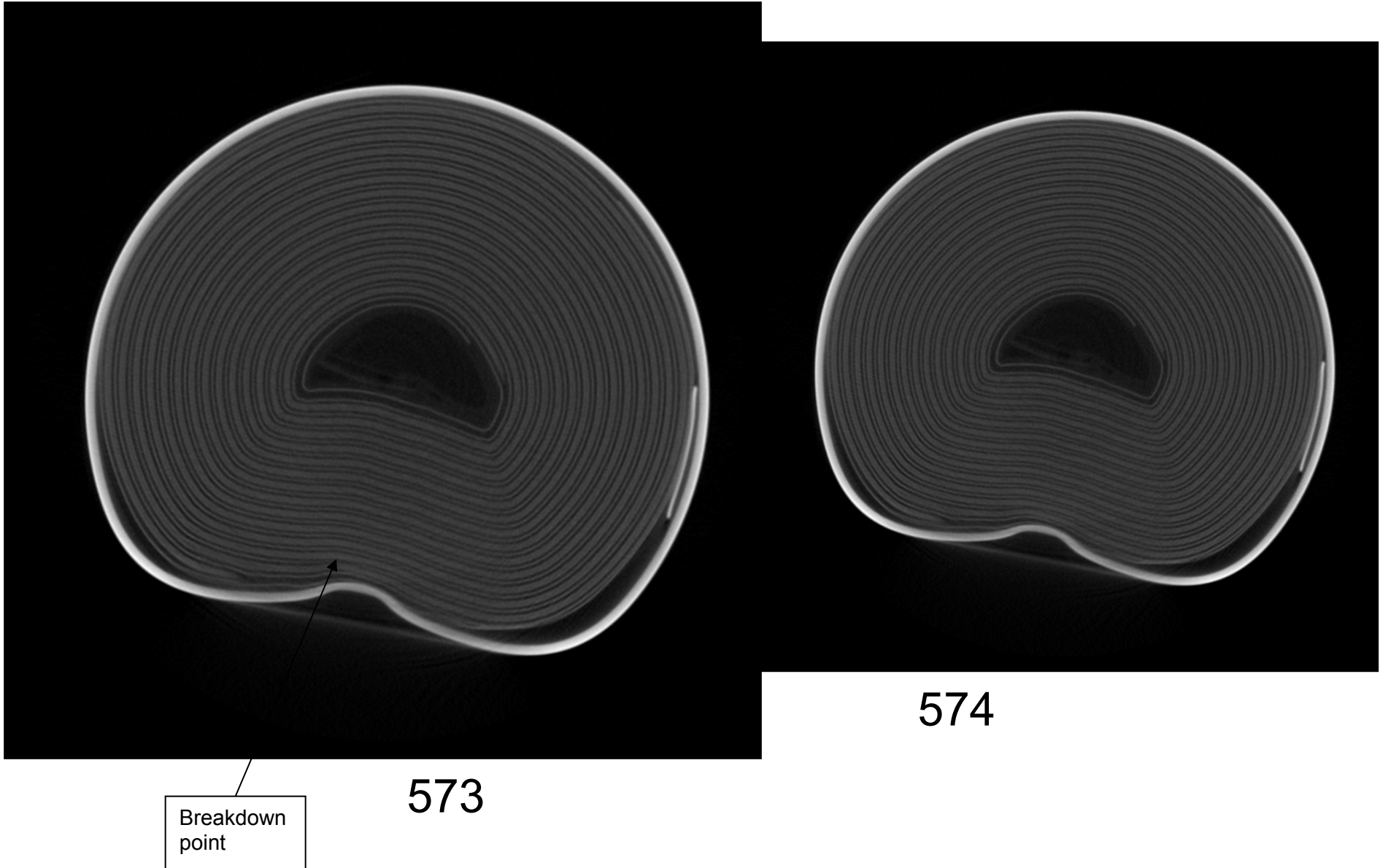


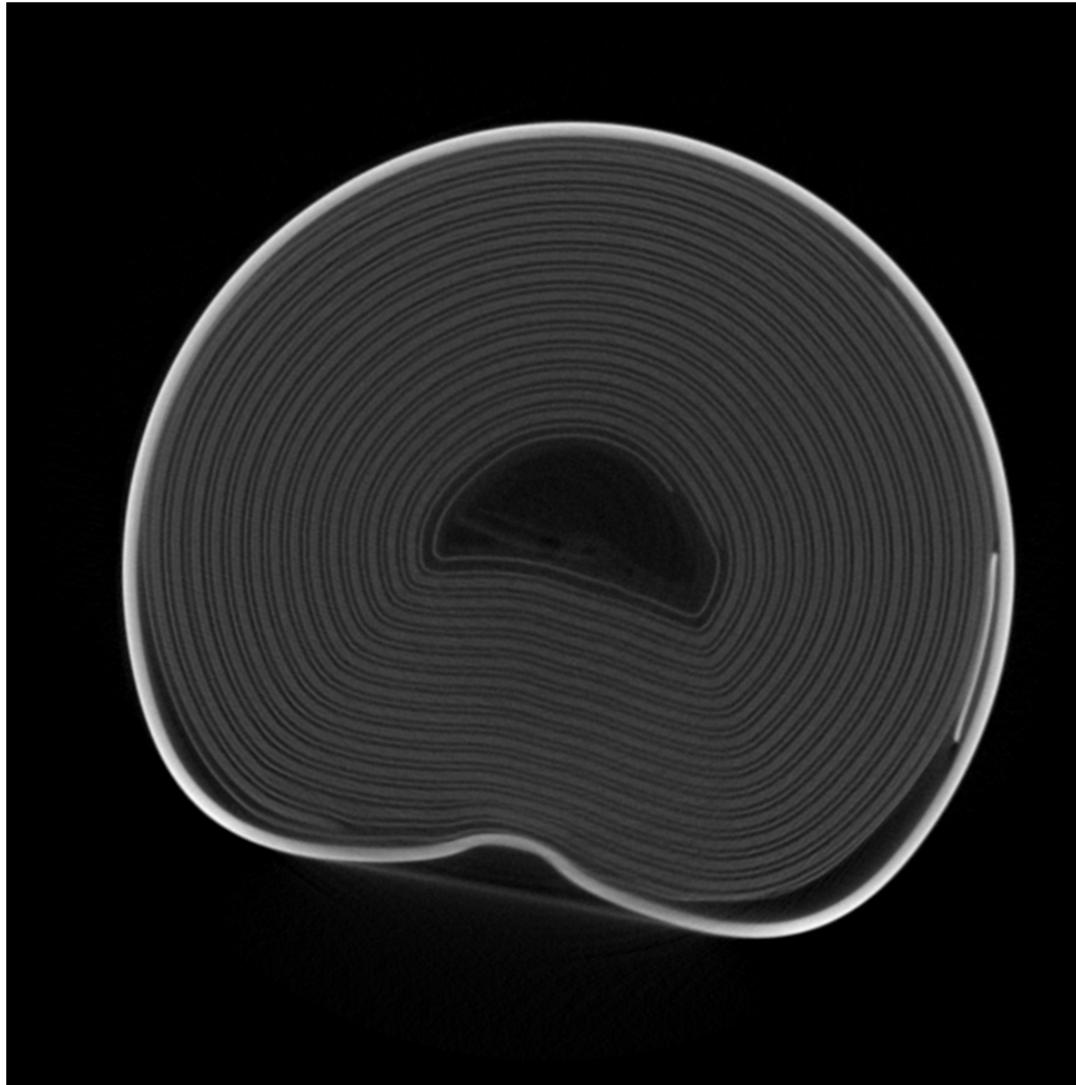
Image 572

Start of
Breakdown

Cell 63 1/8" rod



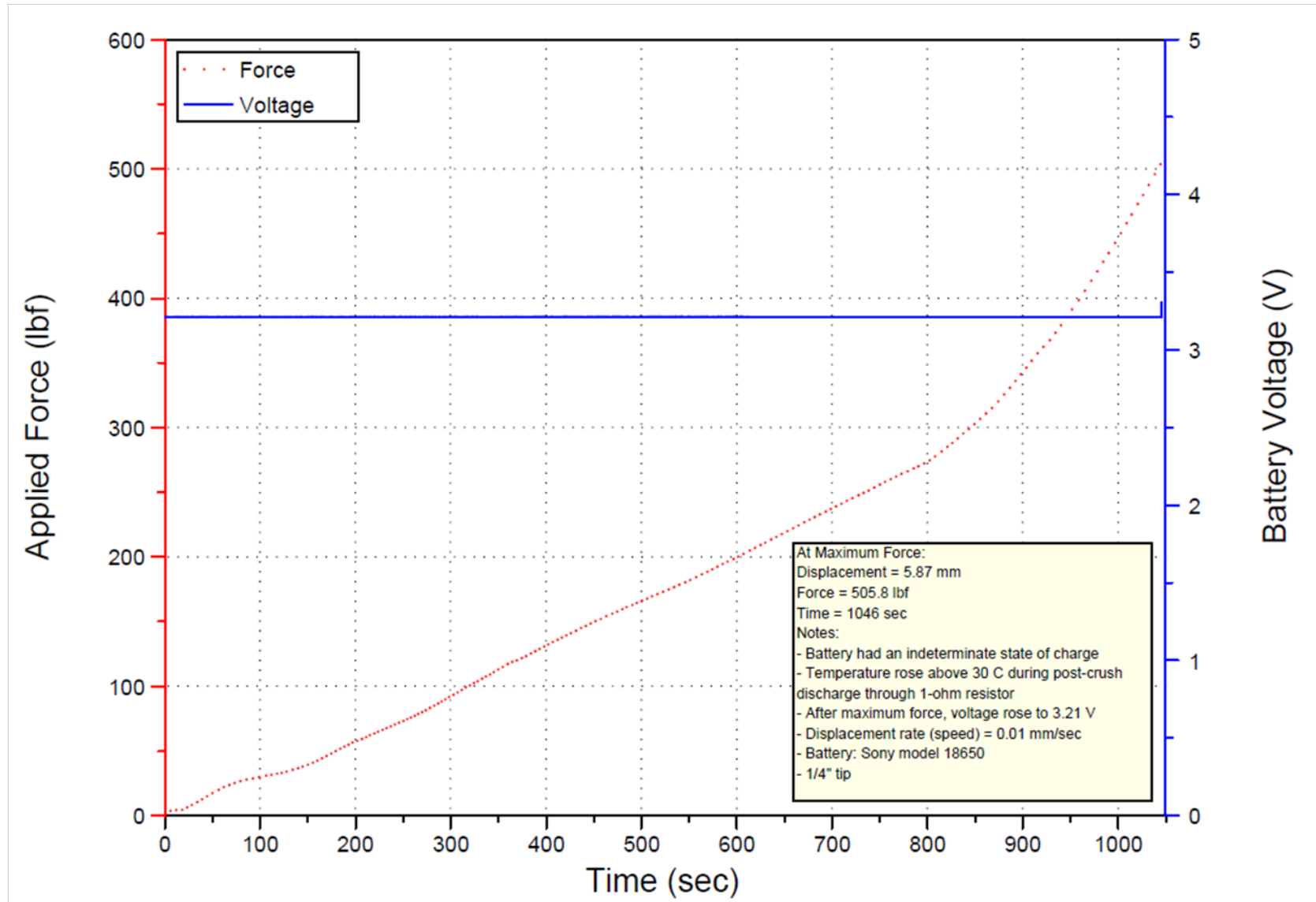
Cell 63 1/8" rod



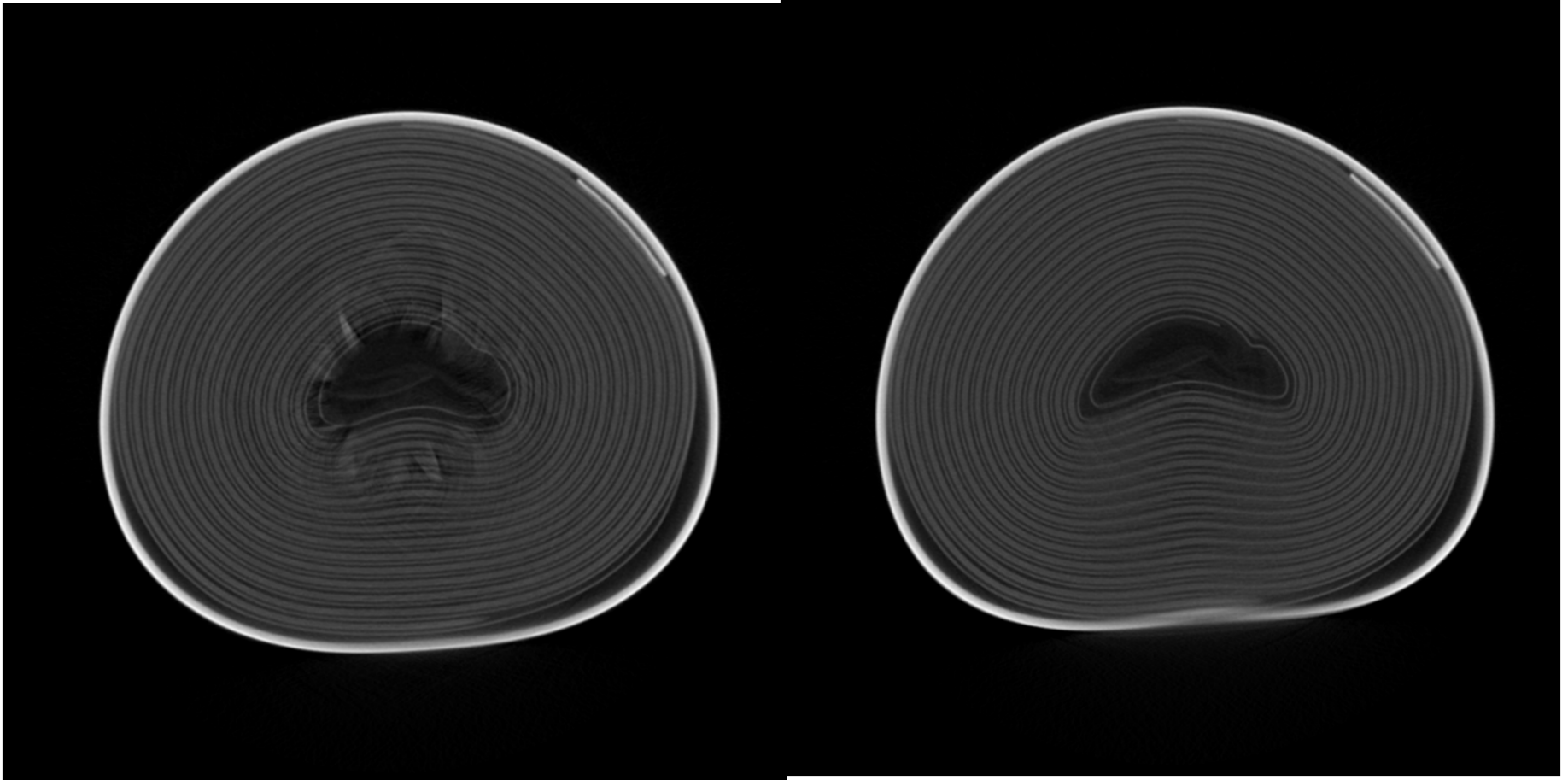
575

Distinct electrode separation observed again in this.

Cell 64



Cell 64 1/4" rod

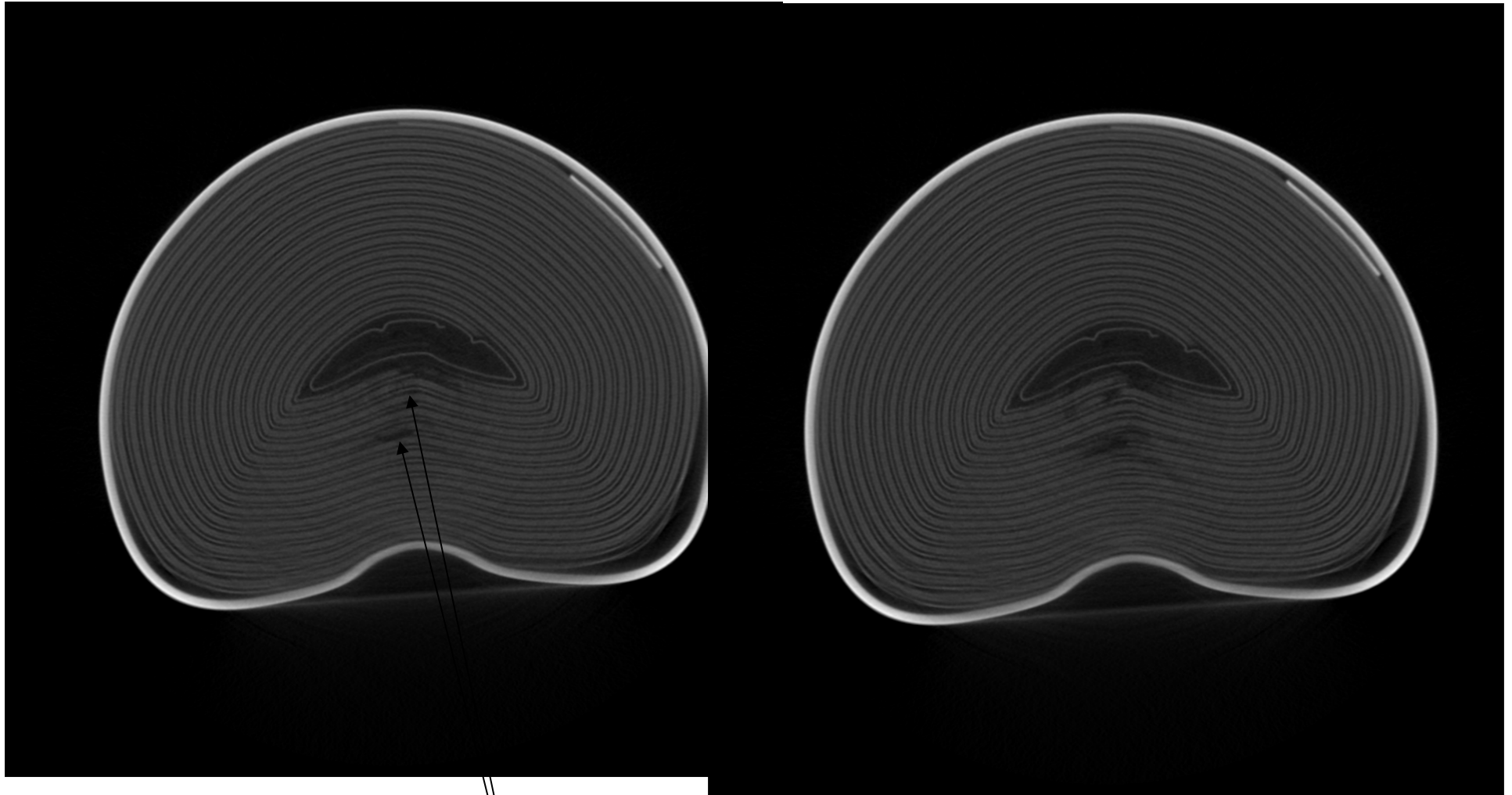


393

476

Note more shape change internal to the electrode roll than external to the roll.

Cell 64 1/4" rod



640

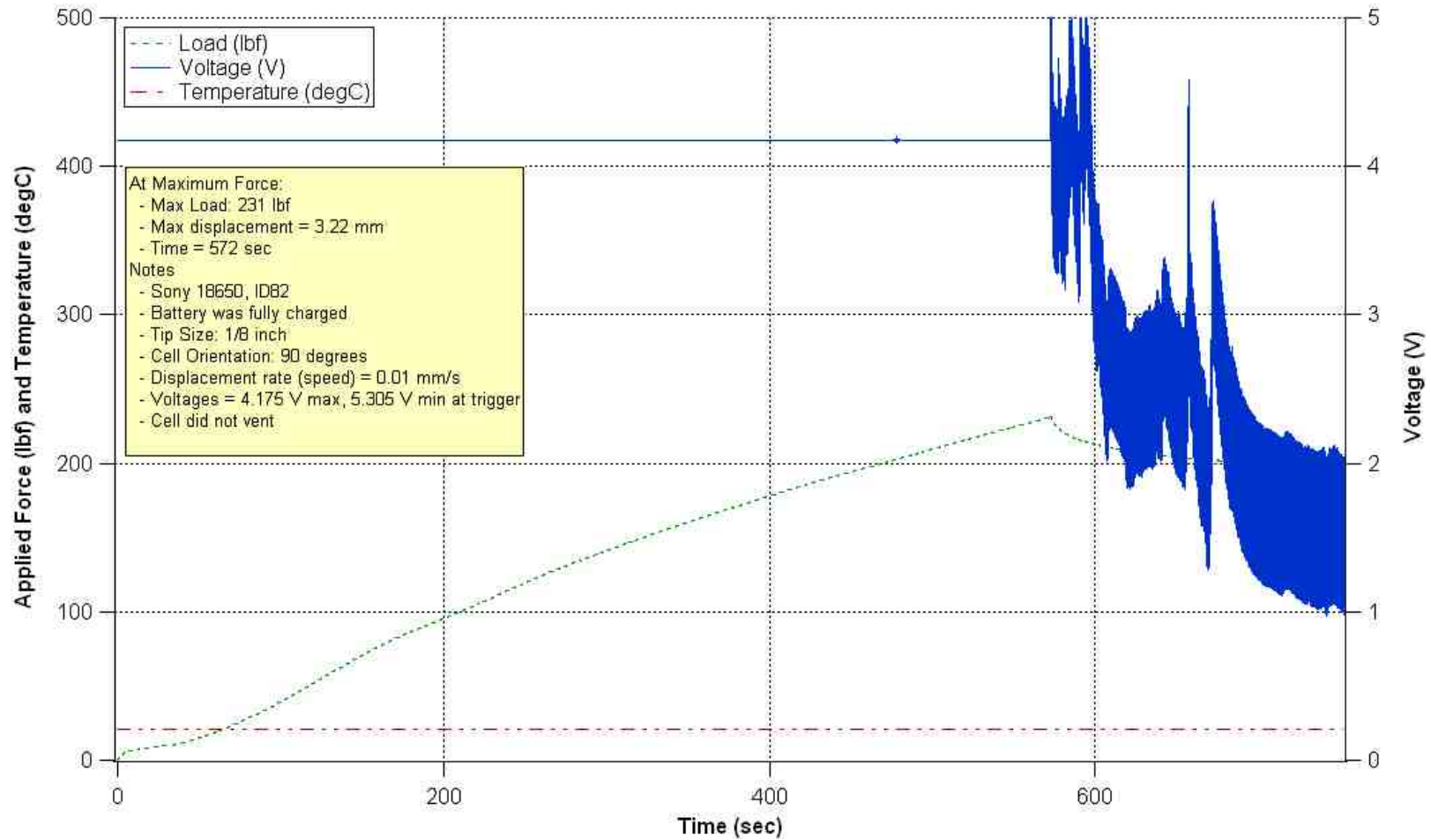
Electrode
damage

Breakpoint

Other Findings

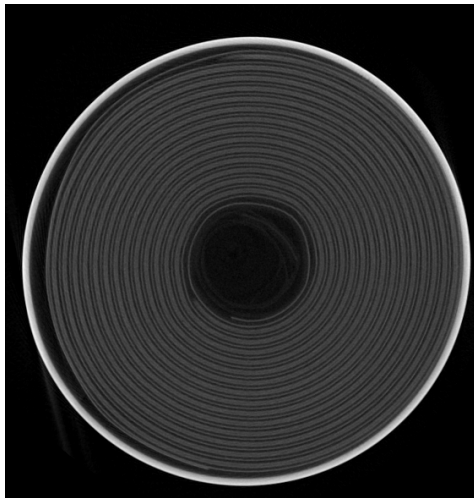
- Erratic voltage readings or no cell venting at 100 % SOC, indicated an issue with test equipment
 - Unclean crush rods, dirty voltage sense contacts, etc.
- Rods had to be cleaned and polished periodically since the heat would affect the tips and the vent products would adhere to the tips causing uneven tip surfaces.
- Thorough cleaning of the test setup is carried out after every cell test and the test setup is removed and cleaned to a higher cleanliness level after every few cells to confirm that the contacts and interfaces in the test setup were at a high level of cleanliness to be able to get repeatable and reproducible results.

Cell 82



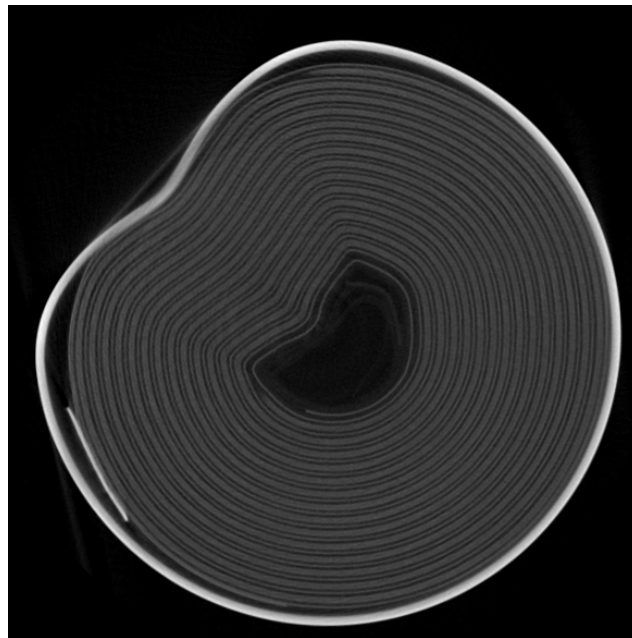
Cell 82 (1/8") no vent

⊥ 90 deg to tab
500 cycles

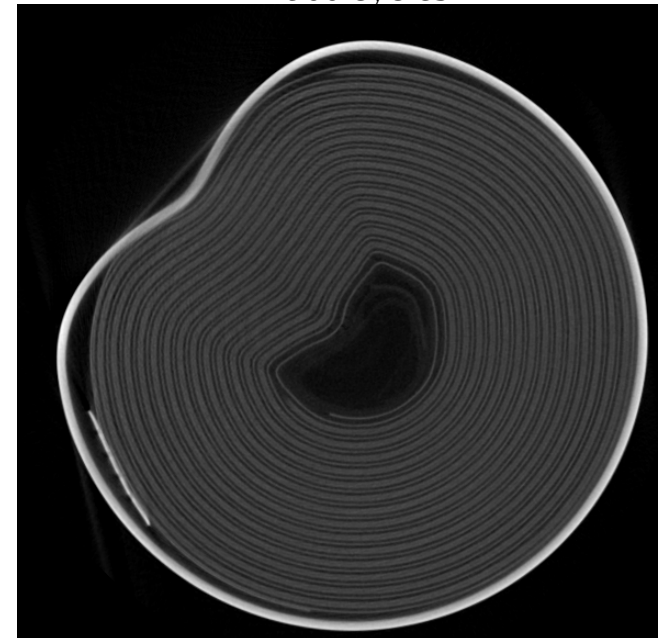


1

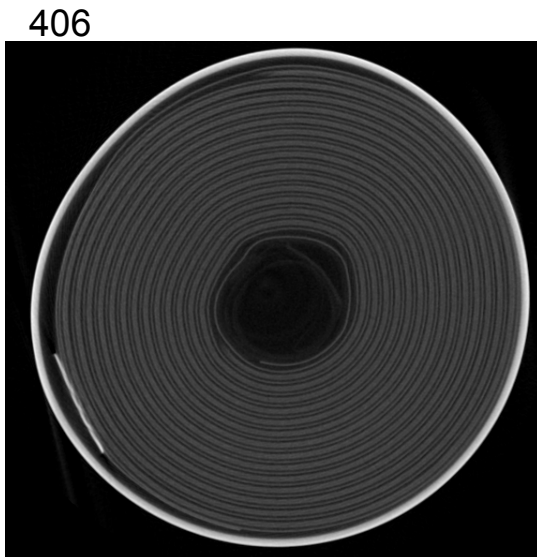
No internal short
was observed due
to the rod losing its
polished tip



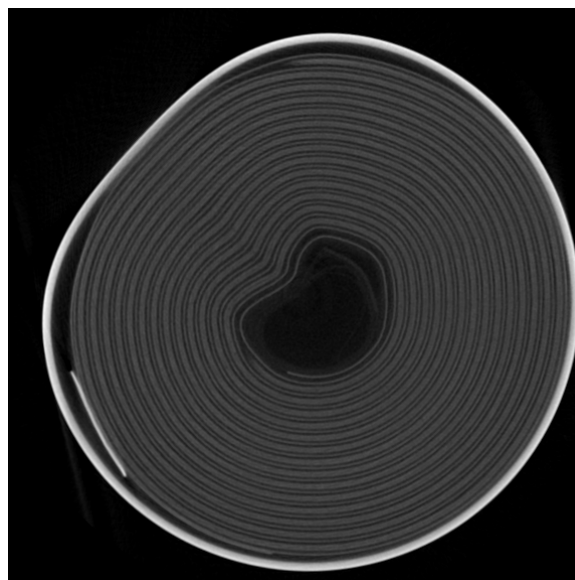
634



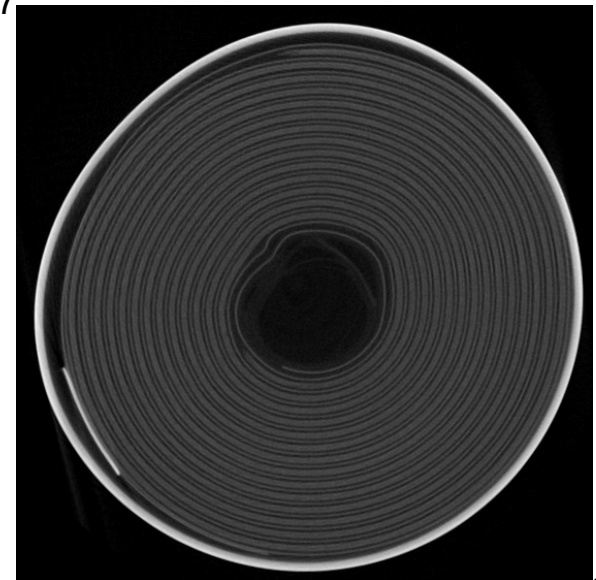
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406

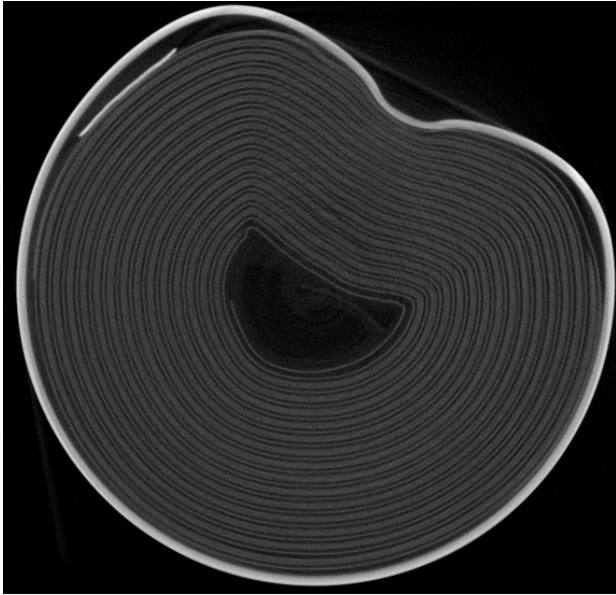


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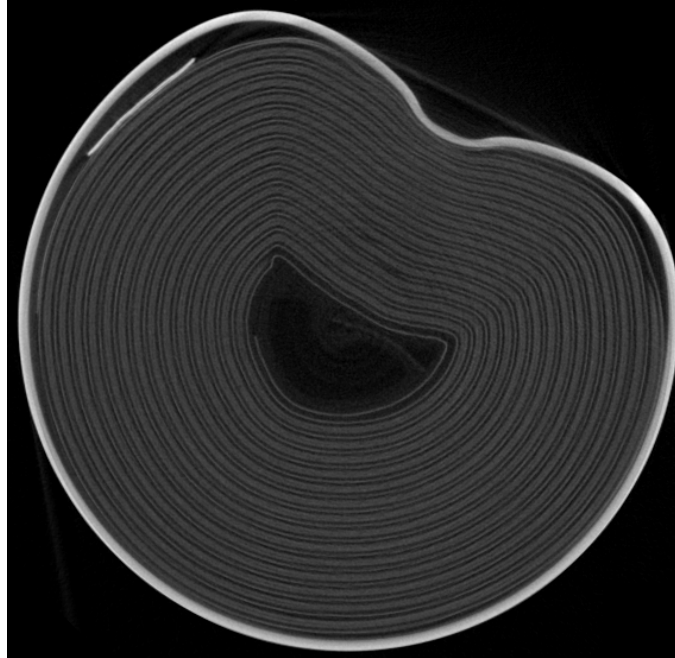


961

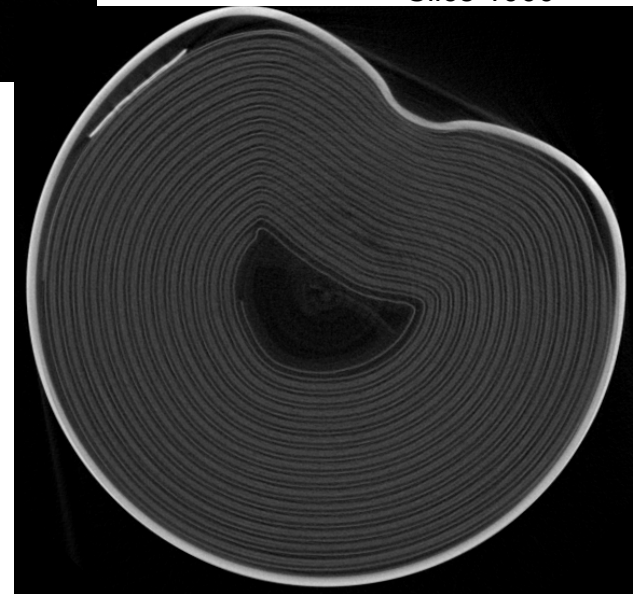
Cell 81 (no vent; 2 cycles)



Slice 998



Slice 999



Slice 1000

Other Observations

- Even with the 1/8" rods, the radius of curvature of the tip was important. With the wider tips, the test was incomplete, no internal short occurred. With the thin tips, penetration of can occurred. The medium curvature tips were the best.
 - NASA designed rods using a type of stainless steel.
- Cells that underwent 1000 cycles showed a range of capacity losses (16 to 24 %). The cells that had capacity loss of 19 % or more, did not undergo thermal runaway during crush test.
- Cells of indeterminate or < 50 % SOC did not undergo thermal runaway.
 - Cells from the same batch of indeterminate SOC were (discharged and then charged and discharged again) found to be at approx. 50 % capacity (1.12 Ah versus 2.3 Ah after full charge)
- Overcharged cells consistently went into violent thermal runaway several seconds after the voltage drop occurred.

Summary

- CT scans indicate that 1/8" blunt rod is better than the 1/4".
- The lower speed for crush 0.01 mm/sec provided more consistent results.
- There is no difference in test results based on location of crush.
- The voltage drop is too fast to be able to use it as a criteria for the standard but the 500 mV change seems to be a reasonable point to stop the crush. 100 mV is in the noise - level and the results with that value as a limit were not consistent.
- Cells at lower SOC exhibit benign results compared to those at full SOC. This result has been consistent and reproducible.
- Cells of indeterminate state of charge after storage for long periods did not cause a thermal runaway, low capacity/energy content.
- Cells at 50 % SOC did not cause a thermal runaway.
- Cells at 0 % SOC did not cause a thermal runaway.
- Cycled cells that had a loss of greater than 19 % capacity did not result in venting or thermal runaway.
- So far, the results have been very consistent with the results obtained from NASA-JSC's old crude test setup.

NASA - JSC's Approach

- NASA- JSC has used this crush test method for more than 13 years to determine a cell design's tolerance to internal shorts.
- Results from the tolerance test dictated the type of screening method to be used for flight acceptance testing of batteries.
- 100 % of flight batteries undergo flight acceptance testing.
- Except for button cells and alkalines, all batteries undergo vibration testing
- Batteries that are tolerant to internal shorts (aqueous battery chemistries such as NiMH, NiCd and Ag-Zn) undergo workmanship vibration.
- Those intolerant to internal shorts (Li primary and Li-ion) undergo a higher level of vibration to screen for internal shorts. For LiBCX chemistries, X-rays of 100 % of cells was also conducted. (X-rays for Li-ion are not as informative due to the packing density of the cells internally).
- No battery chemistries are eliminated due to their lack of tolerance to internal shorts since on our hazard criticality and likelihood matrix, although this is a catastrophic hazard, the likelihood is very low to remote. Screening methods are used to mitigate such hazards (design for minimum risk approach).

Future Work

- Carry out similar testing on prismatic metal can, prismatic pouch and cylindrical li-ion cells with spinel cathode.

Acknowledgment

Test Team Members

UL: Dr. Mahmood Tabaddor, Dr. Harry Jones and Dr. Thomas Chapin

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